National Aeronautics and Space Administration

Asteroid Robotic Redirect Mission (ARRM) Solar Electric Propulsion (SEP) Other Trades Study (OTS)

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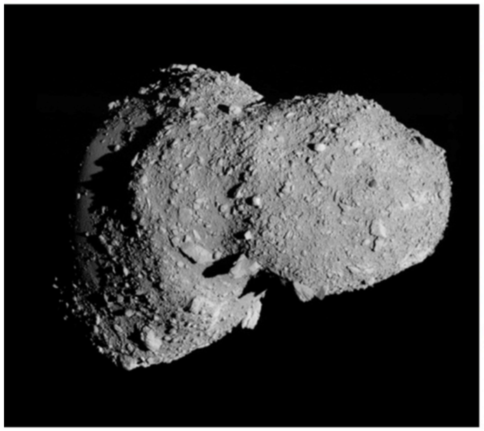
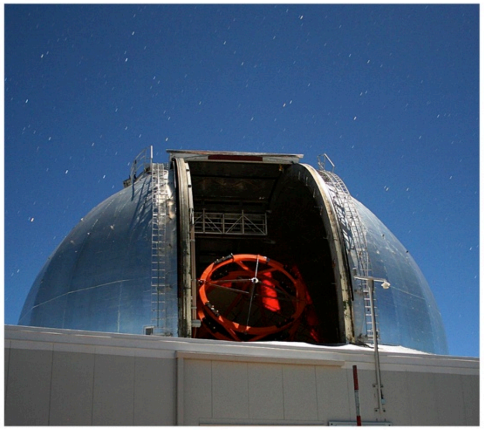




SEP "Other Trades" Study Background

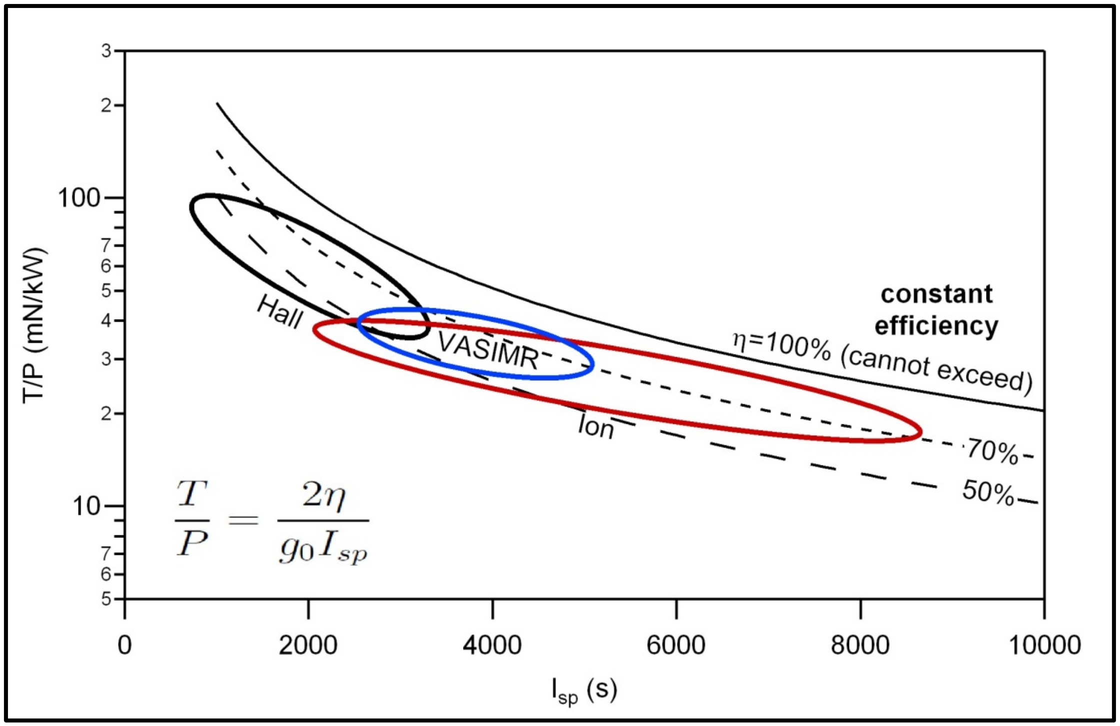
- **Purpose of study is to provide an independent analysis of alternatives to the SEP system proposed by the ARRM team**
  - The SEP OTS analysis focused on alternative methods of accomplishing the mission with different SEP options
  - It is not a detailed examination of the MCT's SEP designs
- **To evaluate alternative methods to accomplish the mission the Team:**
  - Examined ARRM Feasibility Study Team's assumptions and constraints that drove the design (as presented in May), and conducted appropriate trades
    - Power and launch vehicle constraints most significant
  - Performed a due diligence assessment of alternate technical approaches for achieving the propulsive performance requirements for the mission.
- **The OTS team was directed to focus on identifying alternatives that, in order of priority:**
  - Reduced cost, reduced schedule, reduced risk and improved performance; all while maintaining a path to future NASA crewed missions extensibility.
- **The OTS team is providing an initial look at the architecture/mission impacts of alternate SEP technologies**
- **The OTS team is not making SEP system recommendations**

Background

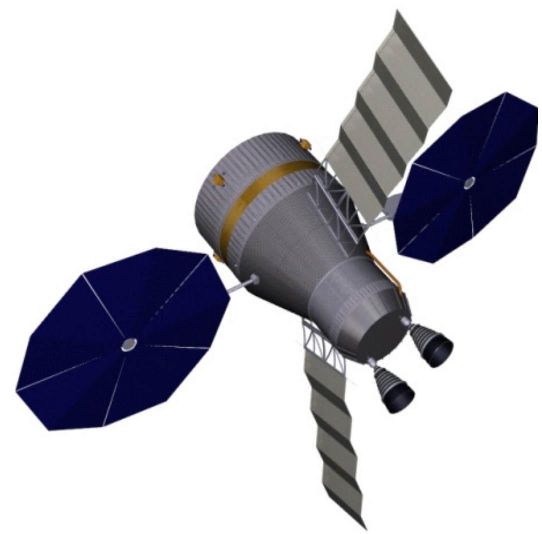
- **The OTS Team is made up of subject matter experts in the areas of electric and chemical propulsion, power, and mission analysis**
  - NESC, GSFC, MSFC, JSC, AFRL, Ga Tech, Aerotech
- **The request for OTS was received by the NESC on 5/2, the study plan was approved by the NESC on 5/16, and an initial Stakeholder out brief took place on 6/28**
- **OTS generated data to allow relative comparisons for SEP type and power level, and for non-SEP propulsion concepts, with the goal of establishing sensitivities.**
  - The team surveyed and documented the state of the art in SEP propulsion
  - SEP systems were assessed at power levels ranging from 40 kW to 250kW
  - Considered: Gridded Ion thrusters, Hall thrusters, VASIMR, chemical systems, and hybrid systems
- **The OTS did not consider targets beyond asteroid 2009 BD**

Propulsive Concepts Assessed

- **Alternatives identified:**
  - Gridded Ion Thrusters (NEXT and NEXIS)
  - Hall Effect Thrusters (4.5, 10, 20, and 40 kW)
  - Variable Specific Impulse Magnetoplasma Rocket (VASIMR)
  - All-chemical and chemical-SEP hybrid systems
  - Non-SEP, non-chemical redirect approaches were also assessed but not found to be viable



High Performance Chemical Stages



Analysis: SEP - General Approach

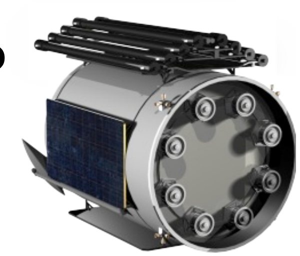
- **Within the context of assessing alternative propulsion options, the team optimized the trajectories to reduce mission flight time**
  - Provide more time for technology and spacecraft development
  - Smooth budget profile
- **The team primarily analyzed cases that did not require the spiral-out element of the mission**
  - Reduces trip time, radiation exposure, and Xenon load (smaller spacecraft)
- **To assess the impact of increased power, an 80 kW power system spacecraft was conceptually designed at the GSFC Mission Design Lab (MDL)**
  - This design, as well as the feasibility team's 40 kW spacecraft design results, were used as the baseline for parametrics on power level and thrusters

Results Observations

- **Generally, higher thrust is beneficial on the outbound leg, and higher Isp is beneficial for the return.**
  - Lower power (40 kW) favors Hall effect thrusters with respect to mission time, spacecraft volume, and overall cost
    - Allows launch on heavy launchers in late 2018 to late 2019
  - Higher power (80 kW – 100 kW) allows more options, the "best" solution being dependant on relative weighting of programmatic performance metrics
    - Allows launch on heavy launchers from late 2018 to late 2020
- **Propellant mass required is largely determined by the system I_{sp} and the launch vehicle used.**
  - Systems using Xenon as the propellant have significant volume advantages due to Xenon's higher density at the storage pressures and temperatures considered.
- **Spacecraft with purely chemical propulsion are too heavy for a single launch of any vehicle projected to be available**
  - Hybrid spacecraft employing chemical and electric propulsion could be launched on planned SLS upgrades, but require significantly more design and development work than pure EP spacecraft

Extensibility

- **NASA's long term human exploration plans would benefit most from demonstration of higher power systems**
  – Crewed missions are projected to require 350 - 400 kW class system, based on 40 – 50 kW thrusters.
  – Ongoing work on arrays can be modified to support 40 kW wings, allowing an 80 kW spacecraft
  – Potential to extend these design concepts to the 300 kW class needs to be further assessed
- **Commercial pull in next decade favors 10–15 kW EP thrusters**
  – Near Earth space operations and time to reach final orbit considerations favors Hall thrusters at this power level.



- **A cost-sharing partnership with industry should be explored for the potential to enable flying two disparate thruster designs that address near and long term needs**

Acquisition Observations

- **Direct launch of the ARM spacecraft out of near-Earth space provides up to 2 additional development schedule prior to launch and reduces funding profile peak**
- **There appears to be several SEP options for performing the mission, each with varying levels of required maturation**
  - NEXT and 8- 15 kW class Hall effect thrusters are the lowest risk technology demonstration options
- **It may be possible to do some budget smoothing with use of a hybrid SEP system**
  - Use both new, high-power (technology demonstration) thrusters and off the shelf thrusters

Summary

- **Major takeaways:**
  - None of the viable systems studied are “ready to go” today
    - Technology maturation can be accomplished within 18 - 24 months for the most mature SEP technology demonstration candidates
    - Paced primarily by Power Processing Unit (PPU) development for the most mature systems
  - Various 40 kW SEP system and hybrid (chemical – electric propulsion) systems will close the mission when launched late in 2018 (or later)
    - Avoiding the spiral out portion of the mission saves up to 2 years of flight time.
  - 80 kW power system reduces mission flight time by as much as 15 months relative to 40 kW launched on the same booster
    - However, there is greater cost and development risk for 80 kW system relative to 40 kW system
  - NASA long-term crewed missions and near-term commercial applications extensibility needs not completely aligned
    - Lower power thrusters/systems more likely to be commercially infused near- to mid-term.